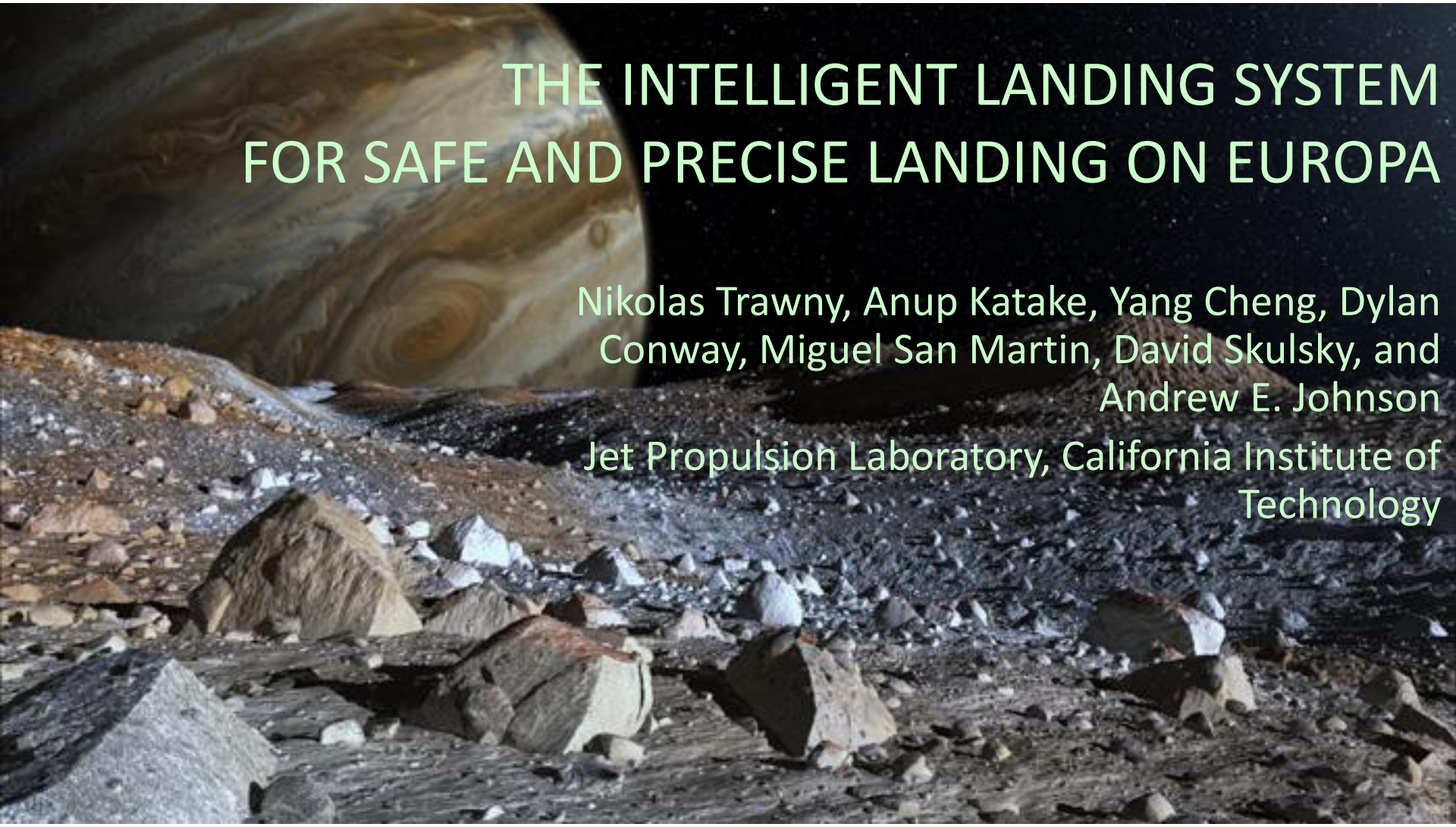


THE INTELLIGENT LANDING SYSTEM FOR SAFE AND PRECISE LANDING ON EUROPA

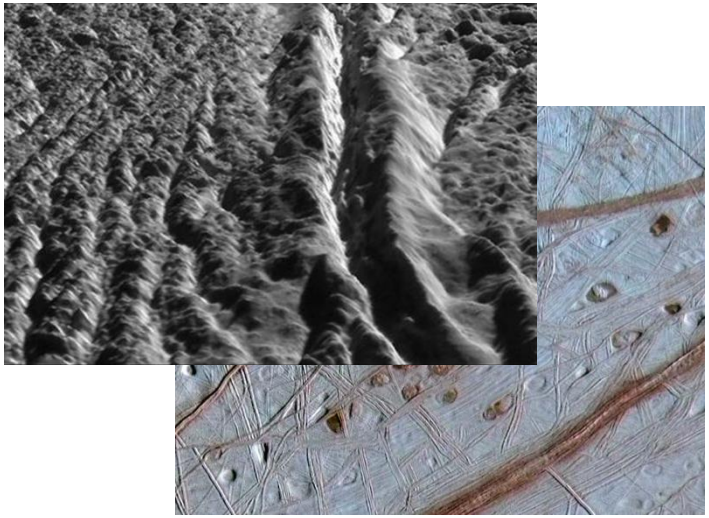
Nikolas Trawny, Anup Katake, Yang Cheng, Dylan Conway, Miguel San Martin, David Skulsky, and Andrew E. Johnson

Jet Propulsion Laboratory, California Institute of Technology

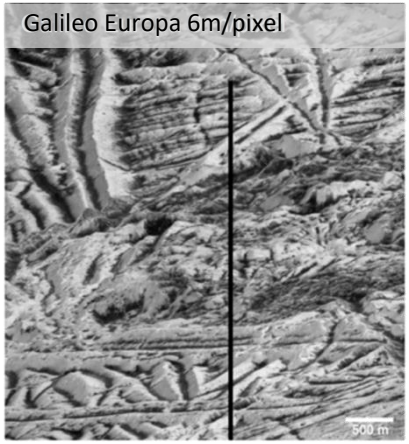
40th AAS GNC Conference, February 2017

Landing on Europa - Challenges

Highly Hazardous & Unknown Terrain



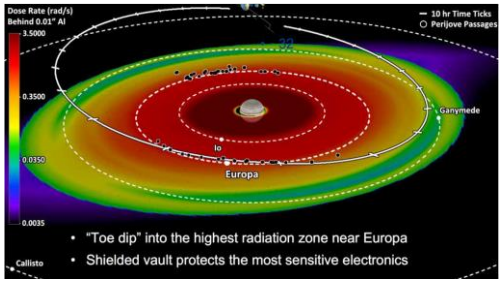
Lack of High-Resolution Reconnaissance Data



Highest Resolution Europa image currently available

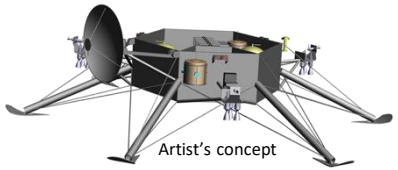
Some Hazards Likely Below Resolution of Orbital Images

Ultra-high Radiation



Safe landing on Europa requires an onboard, autonomous Intelligent Landing System

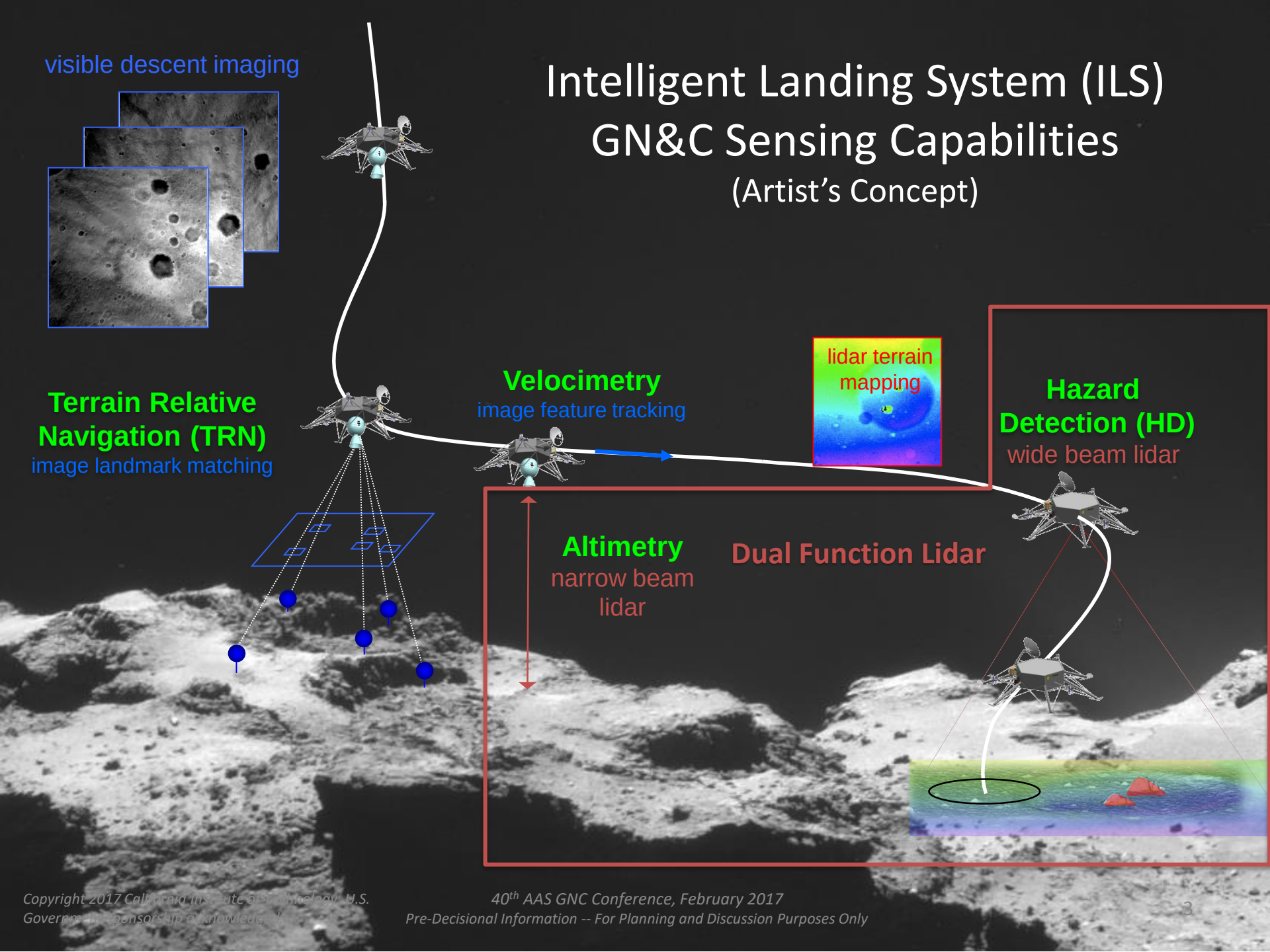
Stringent Size, Weight & Power Constraints



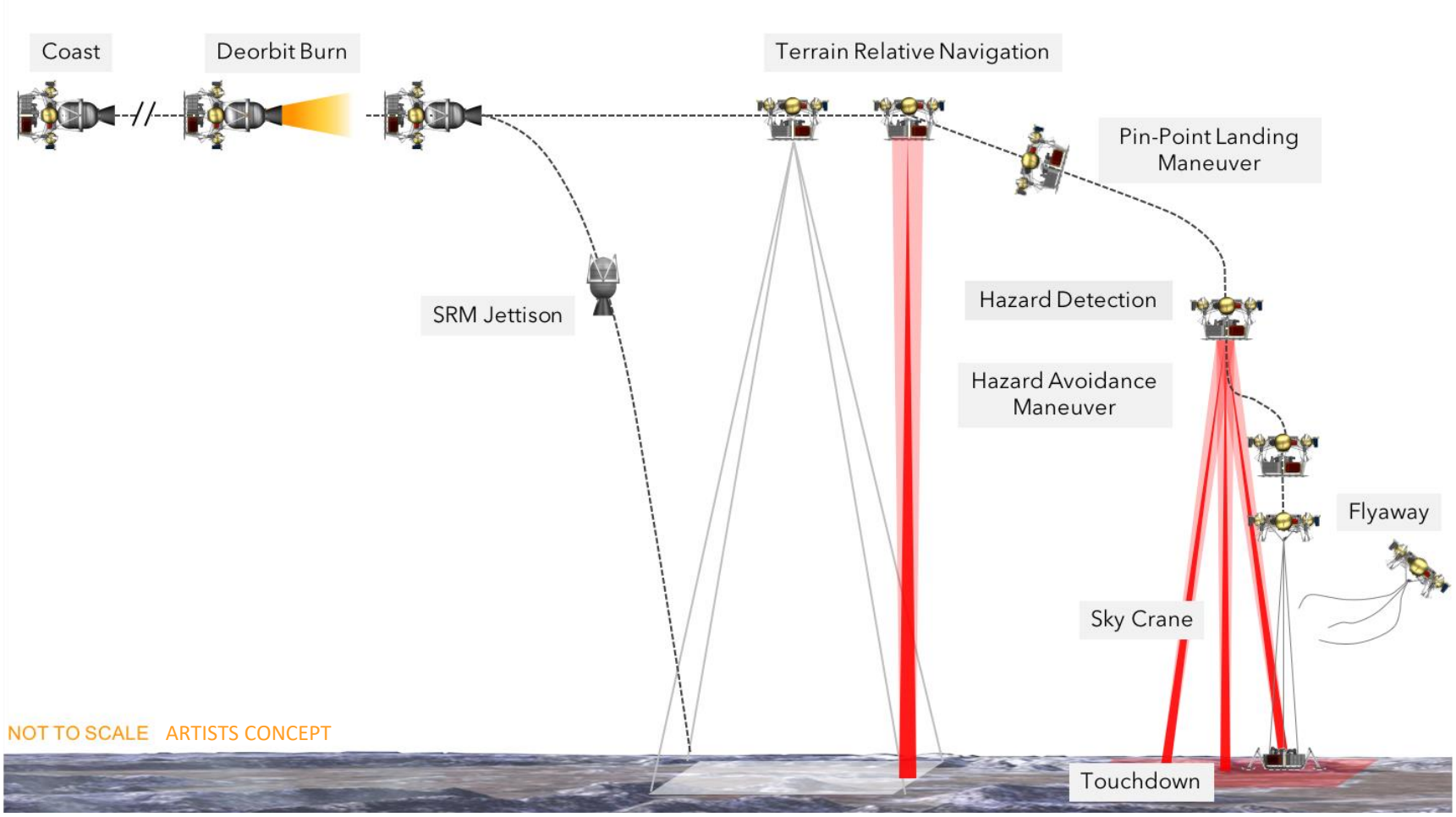
Artist's concept

Intelligent Landing System (ILS) GN&C Sensing Capabilities

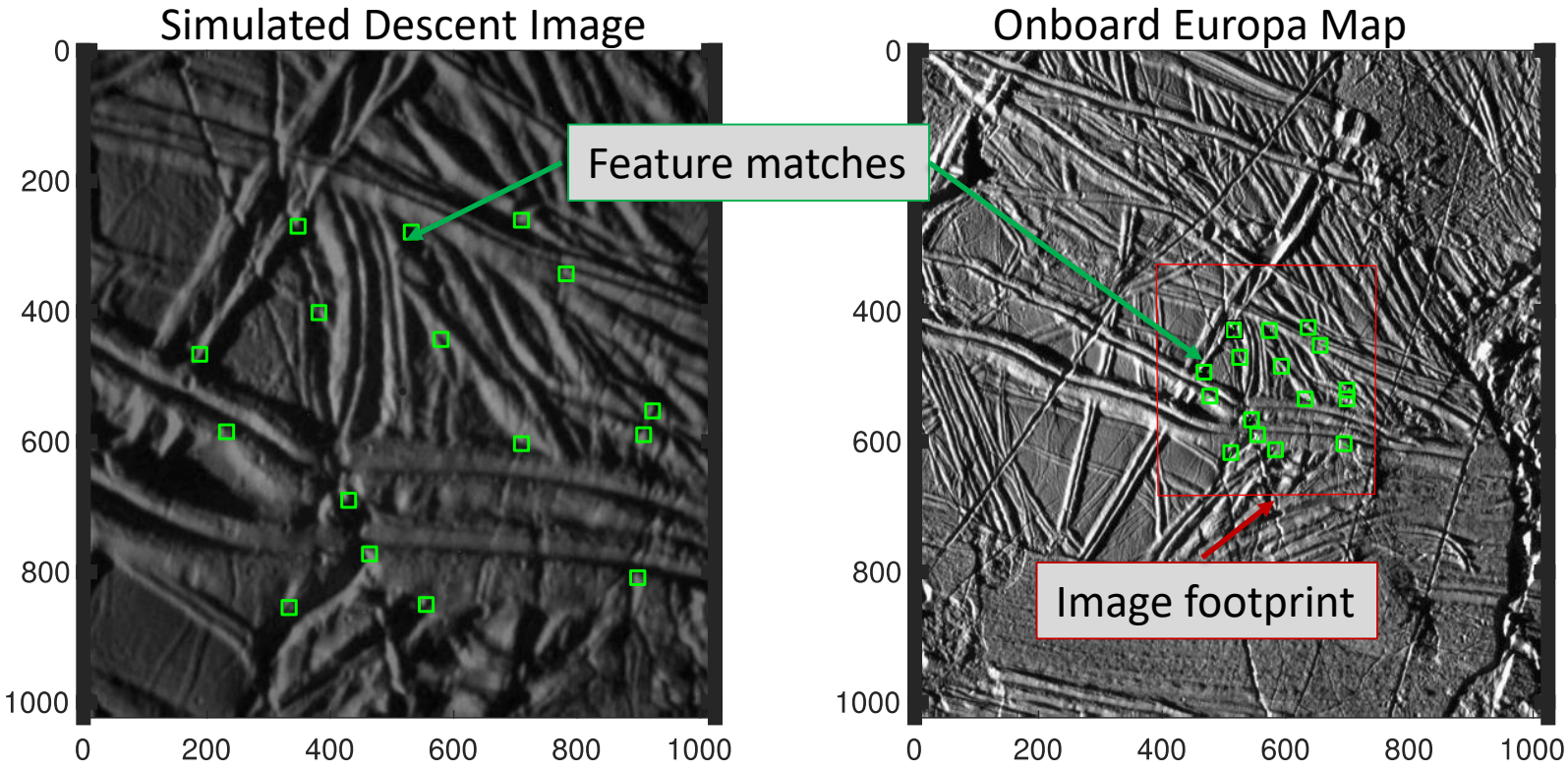
(Artist's Concept)



ILS CONOPS during Europa Deorbit, Descent, and Landing



Map-Relative Localization (MRL)

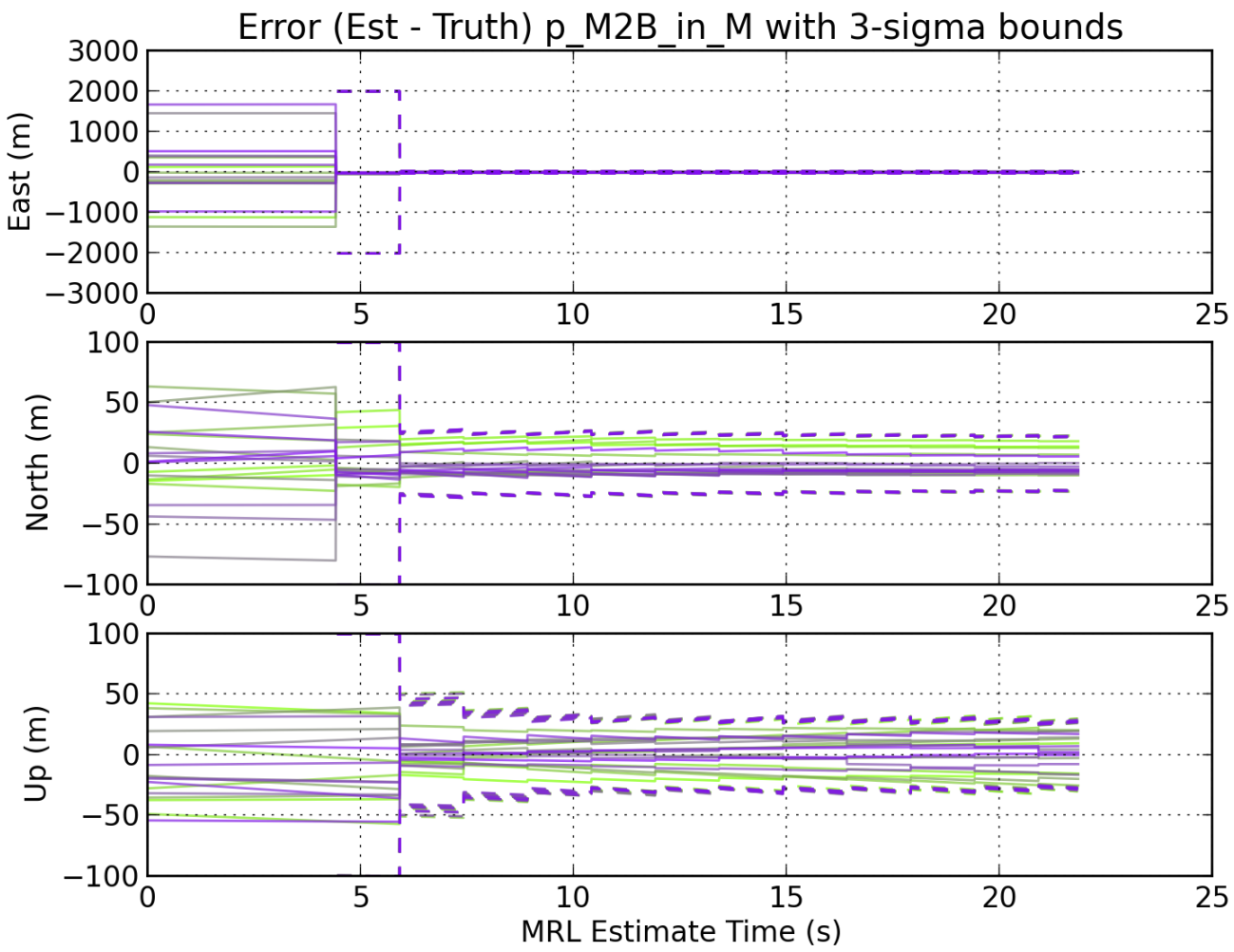


Simulation capability to synthesize, for given trajectory and terrain map

- IMU data
- Camera images
- LIDAR range measurements

Processing capability for given onboard map and sensor data, to execute MRL and evaluate localization performance.

Preliminary MRL Simulation Results



Altitude	5 km
Horizontal Velocity	100 m/s
Map Resolution	16 m/pixel
Initial Downtrack Error	2 km

Preliminary results indicate that 50m position error per axis appears feasible

Note: Not all error sources modeled yet, e.g., map errors, illumination differences, radiation, motion blur, etc

Camera-based Velocimetry

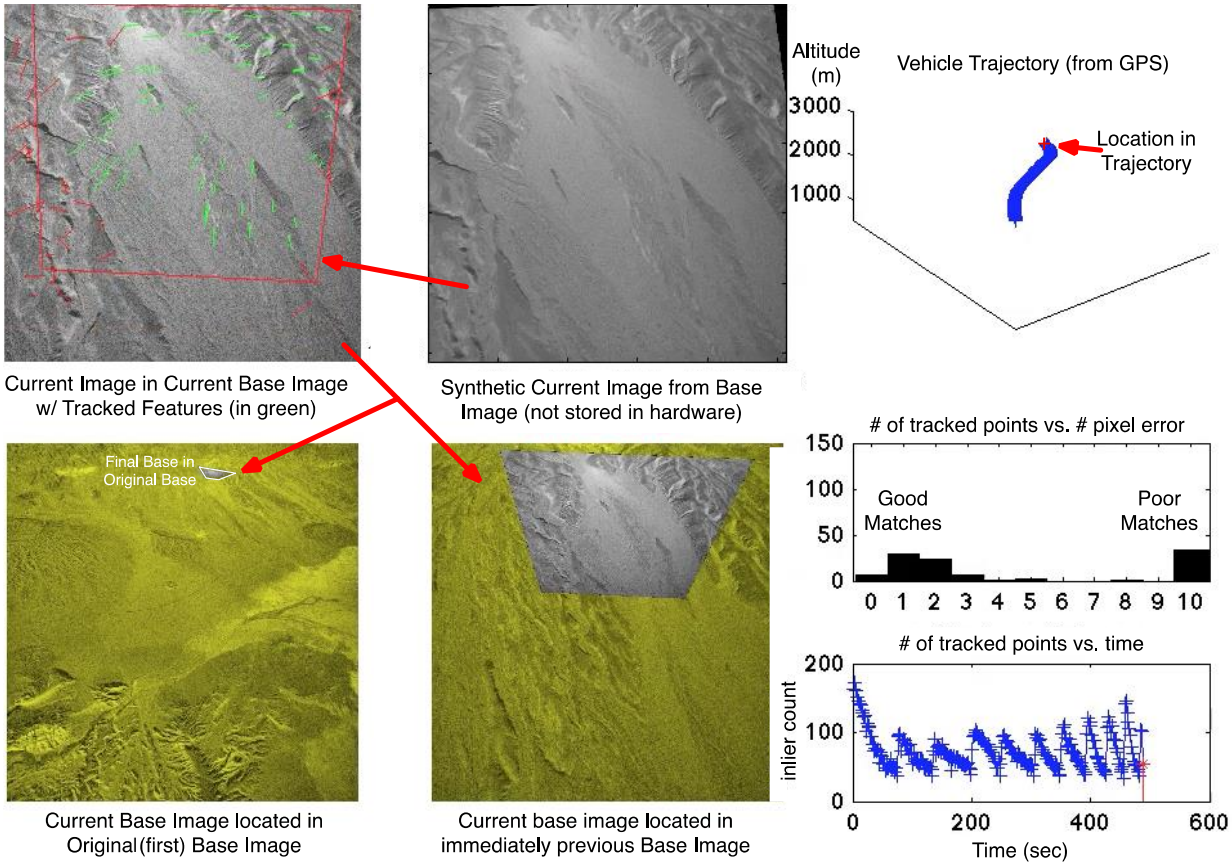
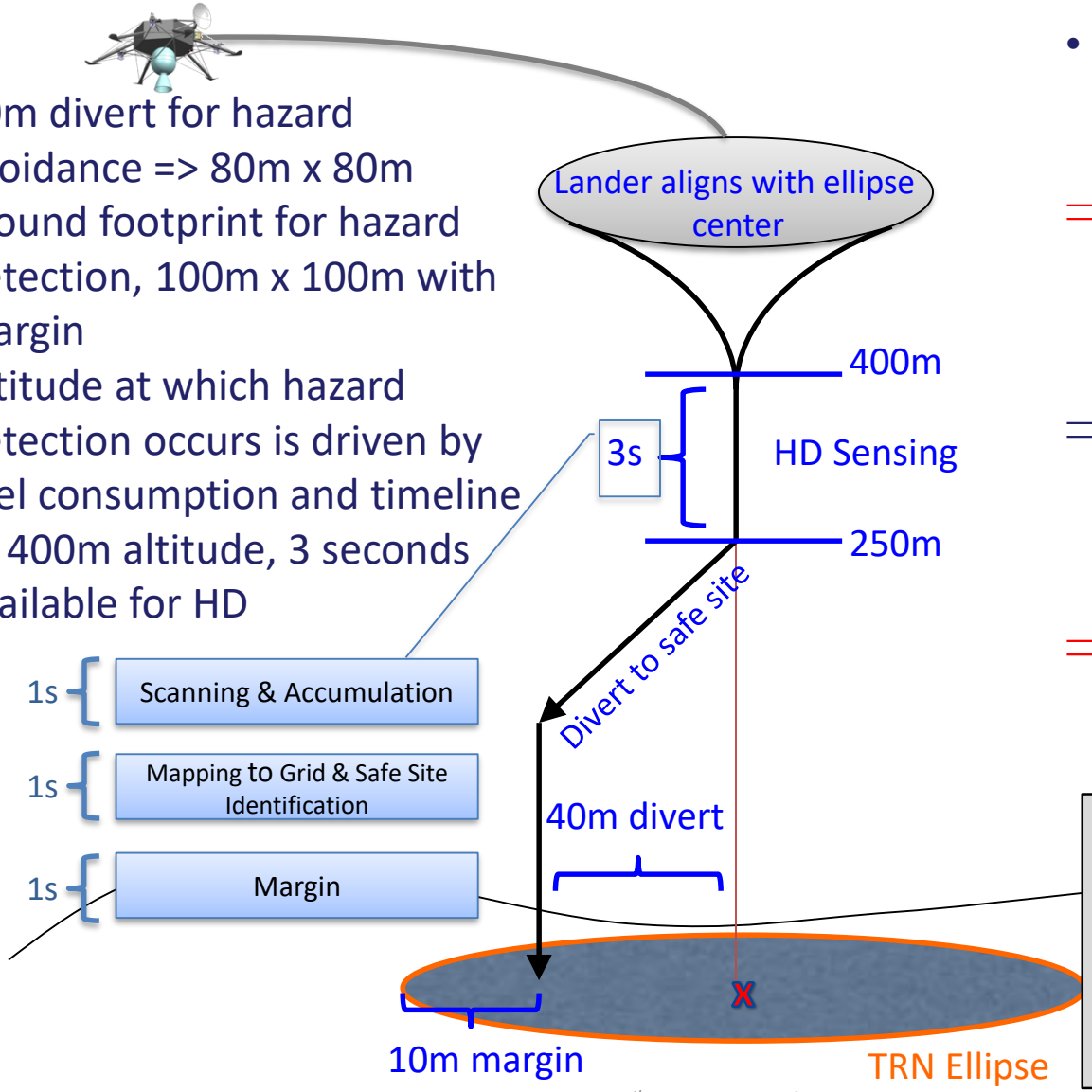


Image-to-image feature tracking results during helicopter field test in Mojave desert

Feature tracking plus altimetry expected to provide tens-of-cm/s level velocity knowledge without requiring an a-priori terrain map

CONOPS – Hazard Detection (HD)

- 40m divert for hazard avoidance => 80m x 80m ground footprint for hazard detection, 100m x 100m with margin
- Altitude at which hazard detection occurs is driven by fuel consumption and timeline
- At 400m altitude, 3 seconds available for HD



- Lander size of 2m x 2m => lander foot size <20cm

⇒ Must have at least 3-4 pixels across the 20cm pad => GSD of 5cm

⇒ Sensor measurements 100m x 100m/(0.05*0.05) = 4Mpixels

⇒ 1seconds of HD => 4M/1s ~ 4Mpixels/s throughput required minimum

Existing LIDAR sensors cannot meet performance requirements for Europa and survive in the extreme radiation environment

4 Steps of Hazard Detection

1. Terrain Mapping
   - Ensure sufficient ground sample distance
   - Potentially oversample for noise reduction
   - Account for vehicle motion during scan

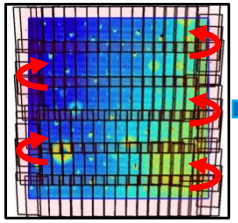
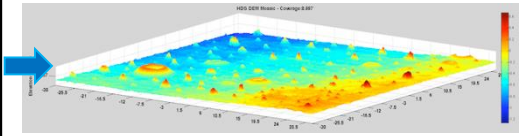
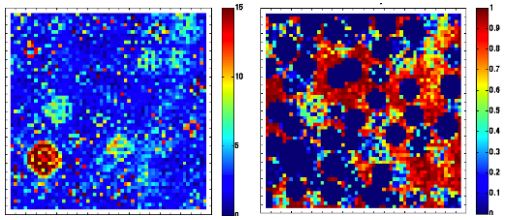


Image Mosaic



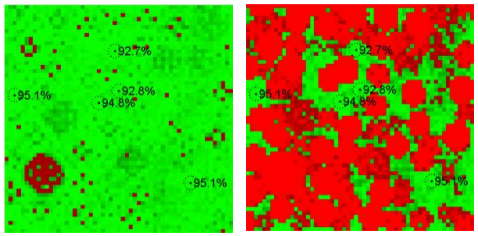
3D Digital Elevation Map

2. Terrain Characterization
   - Slope
   - Roughness (terrain height difference from local plane)



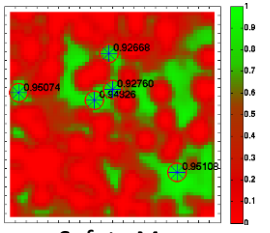
Slope and Roughness Map

3. Hazard Detection
   - Compare local slope and roughness against Lander Tolerances



Slope and Roughness Hazard Map

4. Safe Site Selection
   - Account for Navigation Uncertainty



Safety Map

Hazard Detection requires an accurate, high-resolution 3D terrain map to reliably measure slopes and roughness

Summary

- Landing on Europa represents significant and unique challenges for navigation sensors.
- The Intelligent Landing System is being designed to meet these challenges, and combines four GNC core capabilities: TRN (map-relative localization + velocimetry), altimetry and hazard detection.
- The ILS builds on years of development of safe and precise landing technologies, most notably the Lander Vision System (LVS) baselined on the Mars 2020 mission.
- Significant investments in hardware development necessary, particularly for the LiDAR, to meet performance, address planetary protection requirements, and survive the harsh Europan environment.
- ILS could be enabling for future missions that land on planets, icy moons, asteroids or comets, by allowing to safely and precisely touch down near sites of maximum science value.